IDENTIFYING MARTIAN DISTANT SECONDARY CRATERS BY THEIR EJECTED BOULDERS. G. D. Bart[1] and H. J. Melosh[2], [1]Carl Sagan Center, SETI Institute, 515 Whisman Rd., Mountain View, CA 94043, USA, gbart@seti.org, [2]Department of Planetary Science, University of Arizona, Tucson, AZ 85721, USA.

Summary: Bart and Melosh (2007) demonstrated that distant lunar secondary craters could be distinguished from primary craters by comparing the sizes of the largest boulders ejected from those craters with the size of the crater [1]. The work presented in this abstract tests the validity of that method for use on Mars.

Introduction: Planetary surface ages differentiate sequences of geologic events, revealing clues to that planet's evolution. The crater density dating method is reliable for large craters over broad surface areas. However, spacecraft are beginning to return images at meter scale or better resolution, permitting counts of smaller craters. Can these small craters be used for determining the age of a surface? Some small craters are secondary craters, meaning that the impactor was launched as ejecta from a nearby crater, rather than falling from interplanetary space. Secondary craters near their primary crater can be distinguished by their morphology, because the impact velocity was significantly slower than that of a meteorite impact. Distant secondary craters, however, are morphologically indistinguishable from small primary craters because the ejecta-impactor was launched at much higher velocity. How many of the small craters at a given location are secondary craters? Which ones are the secondary craters? The answer is crucial for reliable age determination.

If most of the small craters are primaries, as some have assumed [2], their production is random in time and space, and hence they can be used to determine surface ages. However, both old lunar results [3] and recent results from Europa [4, 5] and Mars [6, 7] indicate that the small crater population is dominated by secondary craters. Because secondary craters are clustered in time and space, they do not provide a reliable chronometer. Identification of distant secondary craters will help constrain primary production rates of small craters and improve surface age determination of small areas based on small crater counts.

Background: In 2007, Bart and Melosh [1] conducted study of 18 small lunar craters, including both primary and distant secondary craters, and showed that the secondary craters produce larger ejecta fragments at a given crater size than do the primary craters. For the lunar craters they studied, the maximum boulder diameter (*B*) increased with crater size (*D*) according to the power law $B=KD^{(2/3)}$; for primary craters, when *B* and *D* were in meters, *K* was 0.29, whereas for secondary craters, *K* was 0.46 (60% larger). They showed that when considering the lower impact velocity of secondary craters, impact fracture theory in fact predicts that they will produce larger ejecta fragments than primary craters. This result provides an opportunity for distinguishing between primary and secondary craters in high resolution planetary images.

Method: In order to test the validity of this method for use on Mars, our preliminary study compared the boulders ejected from two known distant secondary craters of Zunil with two additional fresh craters presumed to be primary. Approximately 100 of the largest boulders around each crater were measured. Taking the average diameter of the largest five boulders gives *B*. Fitting a ~20 sided polygon to the crater rim five times and taking the average diameter gives *D*. *K* is then calculated from the equation $B=KD^{(2/3)}$, where *B* and *K* are in meters. The HiRISE image numbers, the values of *D, B,* and *K*, and whether the crater appears to be a primary (P) or a distant secondary (S) is listed in the following table.

Image Number	*D* (m)	*B* (m)	*K*	P or S
PSP_004375_1815	152	6.5	0.23	S
PSP_004375_1815	116	6.0	0.25	S
PSP_002542_1765	87	3.3	0.17	P
PSP_002542_1765	67	3.1	0.19	P

Results: These preliminary data show that the martian secondary craters have slightly higher *K* values than the primary craters. However, the difference between the martian primary and secondary *K* values is less than the difference between the lunar primary and secondary *K* values. Whereas the lunar secondary *K* values were 60% greater than the primary values, the martian secondary *K* values are only 30% greater than the martian primary values.

Figure 1 shows a plot of *D* vs. *B.* The lines are plots of *K* at the indicated values. The plot shows the average *K* values for both the martian and the lunar primary and secondary craters.

Discussion: We did not expect this boulder method for distinguishing primary from secondary craters to be quite as effective on Mars as on the Moon. Mars has a higher escape velocity than the Moon (5 km/s vs. 2.4 km/s), but a lower average primary impact velocity than the Moon (10 km/s [8] vs. 19.2 km/s [9]). Thus the martian primary impact velocity is only two times greater than the secondary impact velocity, whereas the lunar primary impact velocity is ten times greater than the secondary impact velocity. These values correlate to peak shock pressures for primary impacts on Mars three times larger than for secondary impacts, whereas on the Moon, the peak shock pressures for primary craters are 40 times greater than for secondary impacts.

It is surprising that the martian *K* values are smaller than the lunar values. As just noted, the average primary impact velocity is lower on Mars than the Moon, and lower impact velocities should produce larger ejected boulders. One difference between the two data sets is that these martian craters are small, strength dominated craters, whereas the lunar craters are larger [1], probably gravity dominated. Crater size is affected by whether the crater is strength or gravity dominated. Expanding this study to include larger martian craters will provide an interesting test of whether we can observe the strength/gravity transition in the boulder size.

Conclusion: We find that the martian secondary craters have higher *K* values than the martian primary craters. However, more data is needed to determine whether the difference is sufficient for determining whether an unknown crater is a primary or secondary.

References: [1] Bart G. D. and Melosh H. J. (2007) *Geophys. Res. Lett.* **34**, L07203. [2] Neukum G. and Ivanov B.A. (1994) in T. Gehrels, M.S. Matthews, and A.M. Schumann, eds., *Hazards Due to Comets and Asteroids*, 359- 416. [3] Shoemaker E.M. (1965) in *The Nature of the Lunar Surface*, The Johns Hopkins Press, Baltimore, 23- 77. [4] Bierhaus E.B., Chapman C.R., Merline W.J., Brooks S.M., et al. (2001) Icarus, **153** 264- 276. [5] Bierhaus E.B., Chapman C.R., and Merline W.J. (2005) Nature, **437** 1125- 1127. [6] McEwen A.S., Preblich B.S., Turtle E.P., Artemieva N.A., et al. (2005) Icarus, **176** 351- 381. [7] McEwen A.S. and Bierhaus E.B. (2006) Ann Rev Earth Planet Sci, **34** 535- 567. [8] Ivanov, B. A. (2001), Space Sci. Rev., **96**, 87 – 104, doi:10.1023/A:1011941121102. [9] Stuart, J. S., and R. P. Binzel (2004), Icarus, **170** 295–311, doi:10.1016/j.icarus.2004.03.018.

Figure 1: Plot of *B* vs. *D*. The red diamonds and lines indicate data collected in this study; the black dashed lines indicate the average of data taken by [1] and extrapolated to smaller crater diameters. The plot shows that the martian secondaries do not plot as high as the lunar secondaries did, although they do plot 30% higher than the martian primary craters. Additional data will reveal whether this difference is sufficient for primary vs. secondary crater identification.

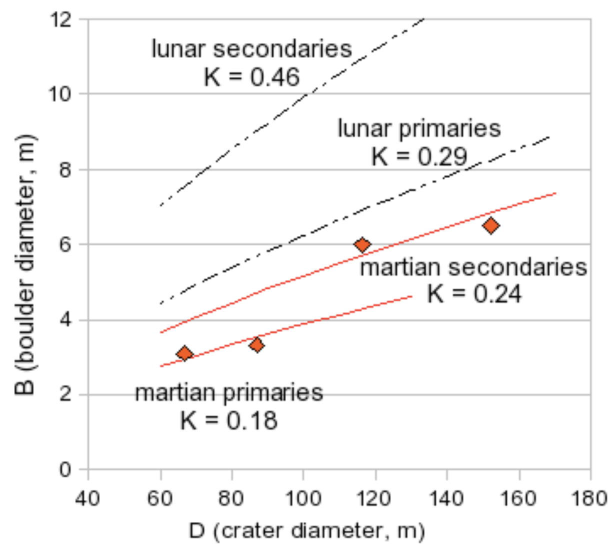

Figure 2: A bouldery martian secondary crater of Zunil from HiRISE image PSP_004375_1815. The crater is 116 m in diameter.